

Impact of Simulation and Virtual Reality on Maritime Education and Training

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Abstract. Rapid technological advancements are reshaping maritime education and training, presenting both opportunities and challenges. As the industry grapples with safety, efficiency, and cost concerns, innovative solutions such as digital training—particularly simulation and Virtual Reality (VR)—are emerging as transformative tools. These technologies offer immersive, engaging learning experiences that enhance competency and preparedness.

Sharjah Maritime Academy (SMA) has been at the forefront of this evolution, integrating cutting-edge Wärtsilä simulation and VR systems into its curriculum. This study assesses the effectiveness of these technologies in maritime education, examining their benefits—including improved engagement, knowledge retention, safety training, and realism—while also addressing challenges such as technical limitations, accessibility, and curriculum integration.

SMA's state-of-the-art training facility employs a range of advanced tools, from bridge and engine room simulators to full-mission simulations and VR applications. By analyzing student and instructor perceptions, this research contributes to the broader discourse on innovative teaching methodologies and sustainable development in maritime education.

1. Introduction

The maritime industry is undergoing a significant transformation, driven by rapid technological advancements and evolving educational needs (Kim et al., 2018). Maritime education and training face distinct challenges, including ensuring safety, efficiency, and cost-effectiveness (International Maritime Organization, 2020). To address these concerns, traditional teaching methods are being reassessed, and innovative approaches are emerging (Lee et al., 2020). Digital training has revolutionized maritime education, offering engaging and immersive learning experiences (Wang et al., 2019). Simulation and Virtual Reality (VR) technologies have become game-changers, providing realistic and interactive simulations that replicate real-world scenarios in controlled environments (Alexander et al., 2015). Sharjah Maritime Academy (SMA) has pioneered the integration of simulations and VR into maritime education.

SMA's cutting-edge facility, equipped with advanced simulation technologies from Wärtsilä, offers immersive training experiences (Wärtsilä, 2020). Research has shown that simulation and

VR integration can enhance engagement and retention, improve safety and reduce costs, and increase realism and situational awareness (Kirkpatrick et al., 2017; Hattie et al., 2017). However, challenges must be addressed, including technical issues, limited accessibility, and integration with existing curricula (Bahari et al., 2020).

This study aims to evaluate the effectiveness of simulation and VR integration in maritime education, identify benefits and challenges, and develop recommendations for enhancement. By examining student and faculty perceptions, this research contributes to the ongoing discussion on innovative teaching methods and sustainable development in maritime education (Maritime and Port Authority of Singapore, 2020).

2. Theoretical Foundations in Maritime Education

2.1 Simulation technologies

Maritime education and training have witnessed significant advancements with the integration of simulation technologies (Kirkley, 2017). Bridge simulation technologies, such as Wartsila NTPRO, Kongsberg Digital Simulation, and Transas Navi-Trainer Professional, replicate real-world navigation scenarios, enabling students to practice and hone their skills in a controlled environment (Wartsila, 2020; Kongsberg Digital, 2020; Transas, 2020). Engine room simulation technologies, including Wartsila Engine Simulation and MAN Diesel & Turbo Simulation, provide hands-on training for engine operations and maintenance (Wartsila, 2020; MAN Diesel & Turbo, 2020).

Virtual Reality (VR) and Augmented Reality (AR) technologies, such as Oculus Quest and HTC Vive, further enhance the learning experience by immersing students in realistic maritime scenarios (Oculus, 2020; HTC, 2020). Full mission simulation technologies, including Wartsila Full Mission Simulator and Kongsberg Digital Full Mission Simulator, integrate multiple simulation modules to replicate comprehensive maritime operations (Wartsila, 2020; Kongsberg Digital, 2020).

Specialized simulation technologies, such as offshore simulation, dynamic positioning simulation, and crane and winch simulation, cater to specific maritime training needs (International Maritime Organization, 2017). The advent of cloud-based simulation technologies, including Wartsila Cloud Simulation and Kongsberg Digital Cloud Simulation, has increased accessibility and scalability (Wartsila, 2020; Kongsberg Digital, 2020).

Other simulation technologies, including multi-crew simulation, ship handling simulation, radar and ARPA simulation, and ECDIS simulation, provide comprehensive training solutions (International Maritime Organization, 2017). These simulation technologies are employed in maritime education and training institutions worldwide, including Sharjah Maritime Academy (SMA), to provide immersive and realistic training experiences (Sharjah Maritime Academy, 2020).

By leveraging these technologies, maritime educators can enhance student engagement, retention, and skills development (Kirkley, 2017).

2.2 Virtual Reality in Enhancing Maritime Training

The Maritime Industry's Adoption of Virtual Reality revolutionizes training methods, prioritizing safety, efficiency, and skill development (Kirkley, 2017). This technological advancement shifts training from conventional classroom-based learning to immersive, interactive experiences (Dziuban et al., 2018). VR's computer-generated simulation of three-

dimensional environments provide realistic and controlled settings for trainees to hone skills without real-world risks or costs (Wartsila, 2020).

Enhancing Maritime Training with VR, complexity and hazardous conditions make hands-on learning invaluable (International Maritime Organization, 2017). VR enhances the learning experience by enabling exploration and interaction with life-like maritime environments (Kirkley, 2017). Trainees navigate vessels, conduct emergency response drills, and apply theoretical knowledge in practical situations, leading to better retention and understanding (Dziuban et al., 2018). The benefits of VR in maritime training are numerous. Enhanced realism and interactivity improve learning outcomes and retention (Kirkley, 2017). Increased safety and reduced risks minimize the potential for accidents (International Maritime Organization, 2017). Standardized training and compliance ensure adherence to industry regulations (Wartsila, 2020).

Impact of VR transforms maritime training, its impact extends beyond innovation to competency development (Kirkley, 2017). This technology reshapes the future of maritime professionals, equipping them with the skills to excel in a rapidly evolving industry (Dziuban et al., 2018). With VR, maritime training enters a new era, characterized by immersive learning experiences, real-world scenario simulation, personalized training and assessment, data-driven training optimization, and enhanced industry compliance and standards (Wartsila, 2020).

3. Discussion

3.1 Addressing the training needs

The maritime industry plays a vital role in global trade, with over 90% of international trade conducted by sea. However, traditional maritime training methods often fail to provide students with the hands-on experience and real-world training they need to succeed. This is where virtual and augmented realities come in, offering a range of benefits including improved safety, increased efficiency, and enhanced engagement. By providing a more immersive and interactive learning experience, virtual and augmented realities can help bridge the training gap in maritime education.

The maritime industry requires a unique combination of theoretical knowledge and practical skills, and traditional training methods often rely on classroom instruction and hands-on training, which can be time-consuming and expensive. In contrast, virtual and augmented realities enable students to practice and train in a safe and controlled environment, reducing the risk of accidents and injuries. Additionally, these technologies can reduce the time and cost associated with traditional training methods, allowing students to learn and practice new skills more quickly.

To explore the potential of virtual and augmented realities in maritime training, this study employed a survey-based approach to gather data from maritime students. The survey consisted of 12 questions designed to assess the effectiveness of virtual and augmented realities in maritime training. By examining the current state of maritime training and the benefits of virtual and augmented realities, this research aims to provide insights into how these technologies can be leveraged to create more effective and engaging learning experiences for maritime students.

3.2 Survey

The survey questions were:

1. How effective are VR and simulation courses in improving practical maritime skills?
2. Do VR and simulation courses enhance understanding of equipment operation and navigation procedures?

3. How well do VR and simulation courses prepare students for standard maritime tasks?
4. Do VR and simulation courses increase confidence in performing maritime tasks?
5. Do VR and simulation courses increase sense of preparedness for real-life sea training?
6. Do VR and simulation courses reduce anxiety or uncertainty about onboard training?
7. How effective are VR and simulation courses in replicating challenging situations?
8. Does the immersive nature of VR add to the learning experience?
9. How helpful are VR and simulation courses in preparing students for emergency situations?
10. Do VR and simulation courses enhance response time and decision-making in emergencies?
11. Do VR and simulation courses save time compared to traditional on-sea training methods?
12. Overall, how satisfied are students with the VR and simulation training experience?"

4. Results

4.1 Survey of Sharjah Maritime Academy (SMA) Students

The survey results reveal a strong consensus among students and faculty members on the effectiveness of Virtual Reality (VR) and simulation training in maritime education. The data, Figure 1, shows that a majority of respondents found VR courses to be beneficial in improving their practical skills, with 38% to 50% strongly agreeing and 35% to 46% agreeing. Similarly, positive feedback was received on the impact of VR training on confidence and preparedness, with 31% to 46% strongly agreeing and 23% to 35% agreeing. The results also indicate that VR training is effective in preparing students for emergency situations, with 31% to 46% strongly agreeing and 23% to 35% agreeing. This is a critical aspect of maritime training, as emergency response is a key component of safety protocols. The ability of VR training to simulate realistic emergency scenarios and allow students to practice their response is a valuable asset in preparing students for the challenges they may face in the maritime industry.

However, there was some variability in responses regarding the time efficiency of VR training, with 31% agreeing and 38% strongly agreeing that it saved time compared to traditional on-sea training. This suggests that while some students found VR training to be a more efficient use of their time, others did not. This may be due to a variety of factors, including the design of the VR training program, the individual learning styles of the students, and the specific goals and objectives of the training. Overall, the survey results show a positive assessment of the VR training experience, with 38% strongly agreeing and 35% agreeing that they were satisfied with the overall experience. This suggests that VR training is a valuable tool in maritime education, and that it has the potential to improve learning outcomes and increase student satisfaction.

Virtual reality (VR) training provides a realistic and immersive learning experience for students. By simulating real-world scenarios, VR training enhances student engagement, motivation, and skill development. This is particularly important in maritime education, where students learn complex skills and procedures. VR training also reduces the risk of accidents and errors. By practicing skills in a simulated environment, students can identify and correct errors before they occur in real-life situations. This is critical in the maritime industry, where accidents can have severe consequences.

In addition to its benefits for students, VR training also improves the efficiency and effectiveness of maritime training programs. By reducing the need for physical equipment and facilities, VR training reduces costs and optimizes resource allocation. Its flexibility and scalability make it an adaptable solution for various training programs. However, VR training also presents

challenges. The requirement for specialized equipment and software can be costly and demands significant technical expertise. Some students may also experience motion sickness or adverse effects when using VR equipment, limiting their participation. To address these challenges, it is essential to carefully design and implement VR training programs. This includes selecting equipment and software that are reliable and easy to use, providing clear instructions and support for students, and monitoring student progress and feedback to identify areas for improvement.



Figure 1. Sharjah Maritime Academy (SMA) Students’ Survey Results

4.2 Students’ feedback and Suggestion for Improving VR and Simulation Courses

Student Recommendations for Enhancing VR and Simulation Courses: To further improve the effectiveness of VR and simulation courses for future maritime students, participants in the study were invited to share their suggestions. The feedback received from the students provided valuable insights into how these courses can be enhanced. Increased Simulator Sessions: Some

students recommended increasing the number of simulator sessions, as these sessions greatly aided their understanding of marine life and the materials required for maritime operations. Furthermore, they suggested that the simulation of emergency situations and ways to deal with these situations should be increased, providing students with more comprehensive training.

Utilizing VR Technology: Another student proposed leveraging VR technology to help maritime students improve their skills. Although specific details were not provided, this suggestion highlights the potential of VR technology in enhancing maritime training.

4.3 Real-Time Feedback and Accessibility

A few students offered more detailed suggestions. They recommended providing real-time feedback to students, enabling them to better comprehend their performance and identify areas for improvement. Additionally, they emphasized the importance of ensuring the accessibility of VR and simulation courses for all students, thereby providing equal opportunities for learning and training. The suggestions provided by the students offer valuable insights into how VR and simulation courses can be improved to better meet the needs of maritime students. By incorporating these suggestions into the design and delivery of VR and simulation courses, maritime training institutions can help ensure that students receive the training and education they need to succeed in the maritime industry.



Figure 2. Sharjah Maritime Academy (SMA) Faculty Members’ Survey Results.

4.4 Survey of Sharjah Maritime Academy (SMA) Faculty members

Figure 2 provides percentages of respondents selecting different levels of agreement for each statement, offering a glimpse into the effectiveness of VR training. Strongly Disagree (0%) and Disagree (8%) responses indicate minimal negative feedback on VR training, while Neutral (Varied Percentages) responses suggest variability in perceptions or a lack of consensus. In contrast, Agree (23% to 77%) and Strongly Agree (23% to 69%) responses indicate a positive reception of VR training. For instance, Statement 1, "VR and simulation courses are very effective in improving my practical maritime skills," garnered a strong consensus, with 69% of respondents strongly agreeing and 23% agreeing. This suggests that VR courses are highly effective in improving practical maritime skills. Furthermore, high levels of agreement were observed in statements related to skill improvement, confidence, preparedness, and replicating challenging situations, indicating that VR training is highly effective in achieving its intended goals.

The positive impact of VR training on preparedness and confidence is also noteworthy, with respondents agreeing that VR training increases confidence and sense of preparedness, which is critical in maritime training. Additionally, VR courses are seen as effective in preparing for emergency situations, which is critical in maritime training, where emergency response is a key aspect of safety protocols. The data also suggests that VR training is a time-efficient alternative to traditional training methods, with respondents generally agreeing that VR training saves time compared to traditional methods.

Finally, the overall satisfaction response is likely to be positive, reflecting the effectiveness of VR courses. While there are areas for improvement, the overall sentiment suggests that VR training is effective, immersive, and valuable. As VR technology continues to evolve, it is likely that VR training will become an increasingly important tool in maritime training and other industries. However, it is essential to acknowledge the limitations of the study, including the limited sample size and self-reported responses.

Future research directions may encompass investigating the long-term effects of VR training, exploring its applicability in other industries, and conducting cost-benefit analyses to assess its economic viability. In conclusion, the empirical evidence strongly supports the effectiveness of VR training in enhancing practical skills, fostering confidence, and preparing individuals for emergency situations, making it a valuable tool in maritime training and other industries.

It is worth mentioning that more than 27 senior level students and 12 faculty members participated in the surveys. The response rate of the survey for students was 27 out of 35 (77%) while for the faculty it was 12 out of 15 (80%). Figure 3 below shows the percentage of surveyed faculty and students agreeing with the survey questions.

4.5 Faculty feedback and Suggestion

Some respondents think that simulation training is an excellent way to develop the skills and competencies required to respond effectively in real-world situations. By providing a realistic and immersive learning environment, simulation training can help to reduce the risk of accidents and errors by allowing trainees to practice and develop their skills in a simulated environment. I agree that simulation training is beneficial, but I also think that it's essential to ensure that trainees take the simulation seriously and do not become complacent. This can be addressed by creating scenarios that are as realistic as possible and providing clear instructions and feedback.

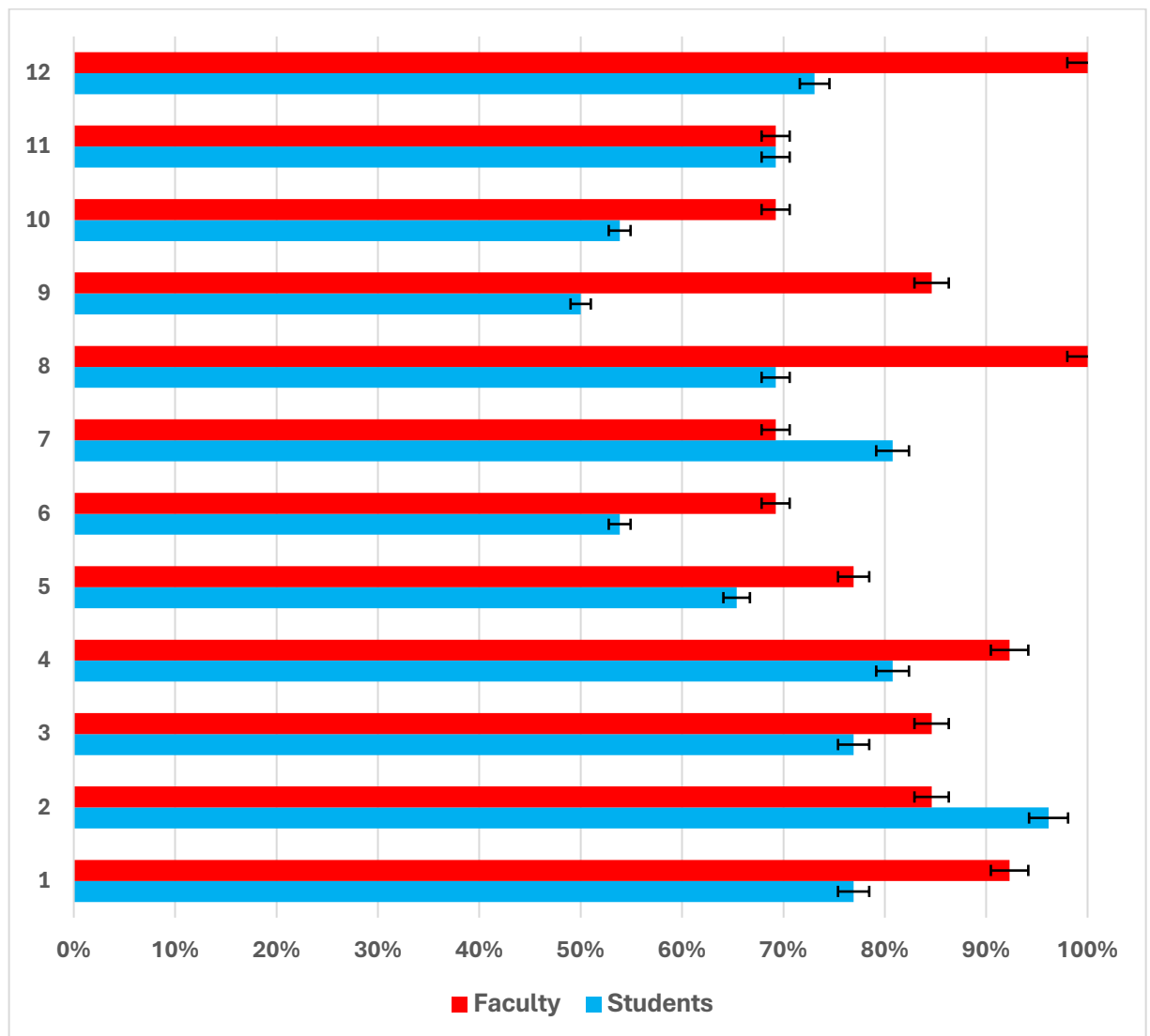


Figure 3. Percentage of Surveyed Faculty and Students Agreeing with the Survey Question

Another respondent pointed out that introducing simulation tools for shipbuilding processes, material testing, and hydrodynamic performance would be highly beneficial. Hands-on training with modern tools such as CNC machines, 3D printers, and laser cutting tools would provide valuable experience. Additionally, collaborating with maritime companies to offer real-world project opportunities would further enhance the learning experience. I also believe that adaptive, hands-on learning approaches can significantly enhance safety training in the maritime industry. By focusing on improved safety and risk management, professionals can develop the competence and confidence to handle real-life challenges effectively.

A third respondent noted that simulation training can help to improve communication and teamwork skills by allowing trainees to practice and develop their skills in a simulated environment. This can help to improve performance and reduce errors. Furthermore, simulation training can help to reduce the risk of accidents and errors by allowing trainees to practice and develop their skills in a simulated environment. I agree that simulation training is beneficial, but I also think that it's essential to ensure that the simulation training program is

aligned with the learning outcomes and objectives. This will provide a clear and focused learning experience.

A fourth respondent pointed out that introducing simulation tools for emergency response training would be highly beneficial. Hands-on training with modern tools such as emergency response simulators would provide valuable experience. Additionally, collaborating with maritime companies to offer real-world project opportunities would further enhance the learning experience. I also believe that simulation training can help to reduce the risk of accidents and errors by allowing trainees to practice and develop their skills in a simulated environment. By providing a realistic and immersive learning environment, simulation training can help to develop the skills and competencies required to respond effectively in real-world situations.

A fifth respondent noted that simulation training is an excellent way to develop the skills and competencies required to respond effectively in real-world situations. By providing a realistic and immersive learning environment, simulation training can help to reduce the risk of accidents and errors by allowing trainees to practice and develop their skills in a simulated environment. I agree that simulation training is beneficial, but I also think that it's essential to ensure that trainees receive feedback and assessment on their performance. This will help to identify areas where trainees may require additional training or support.

A sixth respondent pointed out that simulation training can help to improve safety and reduce the risk of accidents and errors. By providing a realistic and immersive learning environment, simulation training can help to develop the skills and competencies required to respond effectively in real-world situations. I also believe that simulation training can help to improve communication and teamwork skills by allowing trainees to practice and develop their skills in a simulated environment. This can help to improve performance and reduce errors.

A seventh respondent noted that introducing simulation tools for shipbuilding processes, material testing, and hydrodynamic performance would be highly beneficial. Hands-on training with modern tools such as CNC machines, 3D printers, and laser cutting tools would provide valuable experience. Additionally, collaborating with maritime companies to offer real-world project opportunities would further enhance the learning experience. I also believe that simulation training can help to reduce the risk of accidents and errors by allowing trainees to practice and develop their skills in a simulated environment.

An eighth respondent pointed out that simulation training is an excellent way to develop the skills and competencies required to respond effectively in real-world situations. By providing a realistic and immersive learning environment, simulation training can help to reduce the risk of accidents and errors by allowing trainees to practice and develop their skills in a simulated environment. I agree that simulation training is beneficial, but I also think that it's essential to ensure that the simulation training program is aligned with the learning outcomes and objectives. This will provide a clear and focused learning experience.

A respondent noted that introducing simulation tools for emergency response training would be highly beneficial. Hands-on training with modern tools such as emergency response simulators would provide valuable experience. Additionally, collaborating with maritime companies to offer real-world project opportunities would further enhance the learning experience. I also believe that simulation training can help to improve safety and reduce the risk of accidents and errors. By providing a realistic and immersive learning environment, simulation training can help to develop the skills and competencies required to respond effectively in real-world situations.

4.6 *Efficacy Across Learning Domains*

The survey results from both students and faculty members will allow for a structured evaluation of VR and simulation efficacy across three primary learning domains: cognitive, psychomotor and affective which will specifically provide a nuanced understanding of the technology's pedagogical impact.

1. Cognitive Domain Knowledge and Understanding:

This educational technology demonstrates a strong capacity to enhance theoretical enhancement comprehension and knowledge retention which is proved by the high agreement rates on the survey conducted targeting understanding. The immersive visual nature of VR and simulations allows students to interact with this electronic digital learning system.

2. Psychomotor Domain Practical Skills:

The data supports the effectiveness of VR and simulations in developing procedural fluency and practical skills, whereas the simulations provide a safe reliable and repeatable environment for intentional learning and practice purposes of critical hands-on maritime related tasks, e.g. evaluating environmental and ships different maneuverability capabilities where the simulation system can apply different scenarios for students to have pre-brief sessions and de-briefing sessions after task completion.

3. Affective Domain Confidence, Attitude and Resilience:

A paramount goal of maritime training is to build student's confidence, resilient seafarers capable of performing under pressure, whereas this affective shift from apprehension to confidence is a critical outcome. By repeatedly exposing cadets to high stress scenarios in a controlled setting can inoculate students against panic and foster a calmer environment with more decisive mindset when facing real-world challenges.

4.7 *Future Research Directions*

While this study confirms short-term benefits, the long-term efficacy of VR and simulation training requires further and deep planning and preparation that should rely on deep studies conducted to track the skill retention and career performance of trainees using Vr and simulators versus the tradition old methods. Nevertheless, perform a comprehensive cost benefit analysis to quantify the return on investment, considering reduced wear-and-tear on physical equipment, energy saving and improved safety outcomes.

For Long-Term impact assessment a strategic integration of VR and simulation should be guided by recommendations that promise a profound long-term impact on maritime education and the industry at large that could enable a shift towards predictive competency-based training, where potential errors are identified and corrected in a virtual environment before they manifest at sea, this will foster a stronger safety culture across the entire maritime sector, potentially reducing accidents and enhancing operational efficiency. Maritime institutions and training providers can ensure these technologies evolve from innovative tools, fundamental pillars of a modern, resilient and highly skilled maritime workforce.

5. Benchmarking Against international Maritime Education and Training Providers

While this study confirms the effectiveness of SMA's integration of Wartsila simulators and VR, it is instructive to benchmark these findings against leading international maritime education and Training providers to highlight areas of alignment, innovation and for potential future development for SMA.

5.1 Alignment with global leaders:

SMA's approach is consistent with investments made by world-class academies as of World Maritime University (WMU) in Malmo, SWEDEN emphasizes research into simulation for sustainable maritime development, a leading maritime university, a specialized agency of the United Nations as its focus on maritime postgraduate studies and research that undergoes within the framework of the International Maritime Organization (IMO).

5.2 SMA's Position and Unique Value Proposition:

Exceptional strength in foundational and intermediate skills acquisition across cognitive, psychomotor and effective domains by the high student satisfaction and confidence metrics, the challenge and opportunity lie in the advancement towards more multi tasked training and digital driven assessment methodologies.

6. Conclusions

In conclusion, this study provides compelling evidence of the effectiveness of Virtual Reality (VR) and simulation courses in maritime training. By leveraging immersive and interactive learning experiences, VR and simulation courses can significantly enhance learning outcomes and boost student satisfaction. However, the study also underscores the importance of addressing technical and usability challenges that can impede the successful integration of VR and simulation courses into maritime training programs. As maritime educators and trainers continue to innovate and adopt these technologies, careful consideration of these challenges will be crucial to ensure the optimal design and delivery of VR and simulation-based training solutions.

To pace forward it also demonstrates the transformative potential of virtual reality and simulation in maritime training as evidenced by survey data from Sharjah Maritime Academy students and faculty members whereas over 60% of respondents have agreed that simulation training enhanced their practical skills, confidence and emergency response time and preparedness with 38 – 50% strongly endorsing the effectiveness in replicating real world challenges. However, feedback also revealed critical gaps:

1. Technical barriers (e.g. hardware reliability, motion sickness).
2. Pedagogical needs (e.g. frequent simulation sessions and real time feedback).

To address these findings, we propose the following recommendations:

1. Curriculum integration
 - a. Expand simulator sessions: survey data highlighted student demand for the increase of hands-on practice, particularly for emergency scenarios.
 - b. Blend VR with traditional methods: Faculty emphasized the need to align simulations with learning objectives and the use of VR for repetitive skill drill but retain physical drills for muscle-memory.
2. Technical and accessibility improvements
 - a. Upgrade infrastructure: Invest in cloud-based simulations to mitigate hardware limitations as 23% of faculty members addressed accessibility issues.
 - b. Standardize onboarding: provide pre-training tutorials to reduce motion sickness, a concern for 15% of students.

3. Assessment and Feedback

- a. Implement real-time analytics: students requested instant performance feedback, integrate AI driven tools to track decision-making during emergencies, integrate analytic software tools with CCTV cameras to analyse facial response during emergencies and decision-making to evaluate the percentage of pressure applied and body language movement.
- b. Collaborate with industry: Faculty suggested partnerships with maritime companies to align simulations with real-world operational standards to match the Standard of Training, Certification of Watchkeeping for seafarers (STCW) competency compliance.

While VR and Simulation training significantly improve engagement and safety outcomes fulfilling the approach of learning by doing, their success hinges on addressing these operational and pedagogical challenges, therefore by adopting these data-driven strategies maritime institution providers can optimize immersive training and bridge gap between education and industry demands.

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